

## SHORT AND SWEET

## Illusory rotation of a spoked wheel

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**Abstract.** A disk was divided into 16 stationary sectors of different grey levels that stepped around clockwise. When thin stationary spokes of constant mid-grey separated the sectors, the spokes showed robust and striking counterclockwise apparent motion, and when stopped, they gave a brisk clockwise motion aftereffect. The spokes had to match the grey of some of the sectors. We attribute these effects to small displacements across the thickness of the spokes that stimulated hard-wired motion detectors.

**Keywords:** motion perception, illusions, apparent motion temporal resolution.

## 1 Introduction

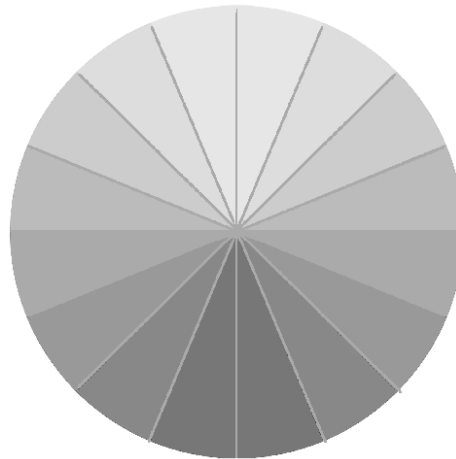
Figure 1 shows a curious motion phenomenon (see movie in [Supplement 1](#)). A disk is divided into 16 sectors of different grey levels, which step around clockwise (CW) in 16 steps at a rate of 1 rev/s. The edges of the sectors never move; only the luminances change. The sectors appear to rotate continuously CW. Note the stationary, thin mid-grey radial lines like bicycle spokes that lie between the sectors. These lines never change their brightness or position, yet when the sectors step around, the lines appear to rotate vigorously counterclockwise (CCW). When the motion was stopped after 20 s, observers reported a strong CW motion aftereffect, produced not by the CW motion of the sectors but by the CCW motion of the spokes. This implies that the 'illusory' rotation of the spokes contains motion energy that stimulates neural motion detectors (Braddick 1974; Anstis 1980; Adelson and Bergen 1985), and the spoke motion must be stronger than the sector motion. In summary, we found that the spokes appeared to move only when they were thin, and when their luminance was similar to the sectors they abutted. This note examines the origins of this 'illusion'.

The position of the spokes is critical; they must run along the edges of the sectors. The luminance profiles in [Figure 3](#) reveal that the motion is located precisely where a sector jumps across a bicycle spoke of exactly the same luminance. This produces a leftward (or CCW) motion signal across the spoke width, as first one sector asserts border ownership of the right-hand edge of a spoke, and then the next sector asserts border ownership of the left-hand edge of the same spoke.

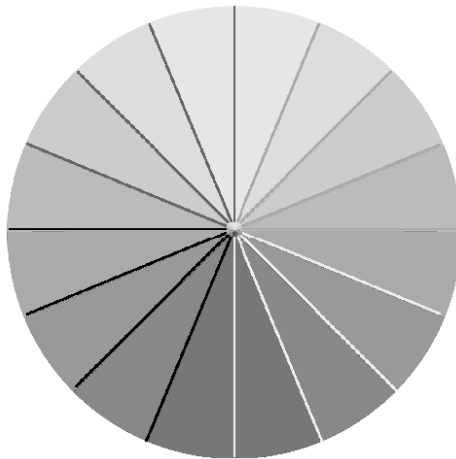
If the display really does contain these moving edges, why call it an illusion? There are three interesting discrepancies between perception and reality: The visual system ignores the overall luminance and timing of the spoke movements, and paradoxically it responds more strongly to small than to large movements.

### 1.1 Overall luminance unimportant

The change in overall grey level across frames ([Figure 3](#)) did not affect the motion percept. In [Figure 3](#) the short leftward arrows show the motions seen when a spoke fuses with adjacent sectors, first with one on its left, then with one on its right. This makes each sector briefly become wider by one spoke width. The grey sector and its adjacent spoke form an edge,



**Figure 1.** The bicycle spoke illusion. Sixteen thin grey spokes separate the sectors. These spokes never change their position or luminance, yet they seem to rotate strongly counterclockwise. When the motion is stopped they give a brisk motion aftereffect clockwise.



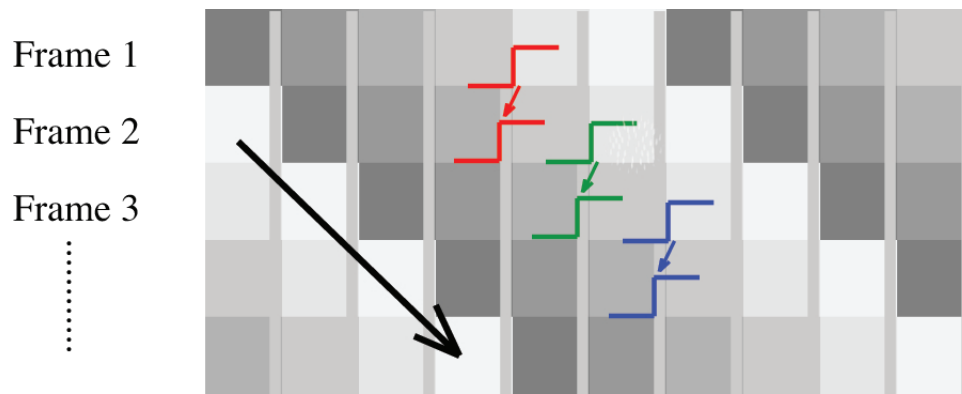
**Figure 2.** In the upper right quadrant the radial spokes match the sector luminances and motion is seen. Where the spokes are lighter than the sectors (lower-right quadrant), or darker (left-hand half) no motion is seen.

which is mid-grey/light-grey in the first movie frame (Figure 3) and dark-grey/mid-grey in the second frame (Figure 3). When the sectors jump to the right, moving through a distance of one sector width, the observer reports this as a single dark/light edge jump, which jumps through one *spoke* width to the *left* (luminance profiles in Figure 3).

Thus contrast, not luminance, drove the motion, as first proposed by Reichardt (1969) and verified by Morgan and Chubb (1999), who measured contrast facilitation in motion detection psychophysically. This explanation requires that the sector luminances should straddle the spoke luminance. This is confirmed by Movie 2 (Figure 2 and Supplement 2), in which different spokes have different luminances. Result: only those spokes that match the luminances of their neighbouring sectors appear to move (top right-hand quadrant of Movie 2). Where the spokes are darker than the sectors (left half of Movie 2) or lighter (bottom right quadrant), no motion is seen.

### 1.2 Timing of spoke rotations not noticed

Observers could see the counterclockwise motion at each spoke but could not see that, although each individual spoke moved through one single tiny step per rotation of the



**Figure 3.** Time runs down the page. Long black arrow shows that sectors step to the right (clockwise). Pairs of colored luminance profiles show that each radial spoke appears to step to the left (counterclockwise), adhering to the adjacent sector first on its left, then on its right. See text. Each horizontal row shows a single frame of Movie 1 (see [Figure 1](#) or [Supplement 1](#)). Squares represent sectors, whose greys jump to the right on each frame (long black arrow). Vertical grey lines represent bicycle spokes that never move nor change. Red lines in Frames 1 and 2 show luminance profiles. Short red leftward arrow shows that the edge at the spoke/sector boundary jumps to the left. Green and blue lines show the same thing for the transitions between frames 2 → 3 and 3 → 4. Note that each of these movements is to the left, but the locus of these movements moves to the right.

sectors, each one did so at a different time. Thus the location of the successive motions was stepping clockwise, but they perceived all the spokes as if rotating counterclockwise as a Gestalt-like unit. This suggests that the local motion detectors are exquisitely sensitive to temporal asynchronies at the edges of the spokes, but the global integration of these local motion signals across large areas has much worse temporal resolution.

When the speed of [Movie 1](#) is reduced to about one-third, namely from 25 to 8 fps, it becomes clear that the spokes do not all move at once; instead, only one spoke in each quadrant moves backward (CCW) on any one step—namely, the spoke that matches the luminance of its neighbouring sector. You can move the scrubber bar of the movie to see this.

### 1.3 Small spoke movements more salient than large sector movements

In [Movie 1](#) ([Figure 1](#)) the small jumps CCW (through one spoke width) are far more salient perceptually than the large jumps CW (through one sector width); for these motions, less is more. It may be that among motion sensors, small receptive fields are more plentiful or more sensitive than large receptive fields (Anstis 2009). Certainly the subsequent motion aftereffect is CW, in a direction appropriate to the small edge motions, not the large sector motions.

## 2 Conclusion

The spoked wheel display brings out some responses of human motion detectors to contrast, size, and time. They are driven by edge contrasts and are indifferent to large overall luminance changes and are often more sensitive to small than to large movements. They are exquisitely sensitive to the small time differences that determine the direction of a local movement, but they are much less sensitive to time when integrating these local motions into a global percept of motion.

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